Volume 4 No. 2
Dec 2007
ISSN 1675-7009

Scientific Research Journal

Institute of Research, Development and Commercialisation

SCIENTIFIC RESEARCH JOURNAL

Scientific Research Journal is jointly published by Institute of Research, Development and Commercialisation (IRDC) and University Publication Centre (UPENA), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

SCIENTIFIC RESEARCH JOURNAL

Vol. 4 No. 2 | December 2007 | ISSN 1675-7009

Scientific Research Journal *Vol. 4 No. 2, 27-39, 2007*

Analysis on the Effect of Land Use Changes on Flooding Using SCS Method and GIS

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ABSTRACT

The research investigated the effect of land use changes on flood estimation by focusing on a widely used method developed by the US Soil Conservation Services, namely SCS Curve Number method. This method was developed to estimate the peak flow and flood hydrograph based on several parameters, one of it is known as the Curve Number (CN). The CN which can be measured effectively using GIS is an indirect measure of soil potential storage and is dependent on the land use. The research explored the feasibility of the method to Malaysian catchments by firstly, analysed the CN in a small urban catchment of UiTM campus at Shah Alam and secondly compared the hydrograph calculated by the method with the observed ones. The results indicated a close proximity of the CN values obtained from the observed rainfall runoff and the values published by the US SCS (around 8 % difference). In addition, comparison between observed unit hydrographs and SCS unit hydrographs for the same rainfall duration indicated that the estimated values of peak discharge from the synthetic method were not very far from the observed values. Finally, it was shown that changes in land use especially during urbanization process would increase the peak flow, hence increase the possibility of flooding.

***Keywords**: Curve Number, GIS, land use, SCS method, flooding*

ISSN 1675-7009

Introduction

Due to the abundant amount of rainfall in Malaysia, flooding becomes one of the most threatening natural disasters especially in a big city like Kuala Lumpur. Changes of land use pattern, which include residential and commercial areas development, road-building, deforestation, and land clearing, is one of the major contributing factors for flood occurrence. Flood estimation and analysis can be performed using several methods like Regional Flood Frequency Analysis, Rational Method and Soil Conservation Services (SCS) Curve Number or simply the SCS method. The SCS method is a simple, widely used and efficient method for determining the amount of runoff from a rainfall event in a particular area [1, 2]. The method is suitable to be applied for flood estimation involving land use changes due to the curve number parameter built in its equations.

Since land use changes occur frequently in a fast developing country like Malaysia, a method of flood estimation which considers the effect of land use changes is essential. In Malaysia, the SCS method has been applied in estimating flood hydrograph and it is becoming more widely applied due to its simplicity and capability in linking its procedures with GIS tools. The runoff curve number (CN) in SCS equation is estimated based upon the soil types, land use practices within a basin and the influences of the antecedent soil moisture condition for specific storm. Despite being applied in many studies for Malaysian catchments, the published runoff CN had been originally developed from many rangeland conditions in the western United States, therefore further studies should be carried out on the feasibility of its application in Malaysian condition

Research Objectives

The main objective of the research is to study the effect of land use changes on flooding using the SCS method and GIS. In order to apply the SCS method, an investigation on its application to Malaysian catchments would be essential. In summary, two specific objectives are to be achieved as follows:

i. Initial study on the feasibility and appropriateness of using the runoff CN for Malaysian catchments.
ii. Application of SCS method and GIS to study the effects of land use changes on flooding.

Methodology

The research methods are divided based on the two specific objectives as given in Section 2. The steps involved in achieving objective (i) include:

- Identification of UiTM Shah Alam campus sub-catchments.
- Determination of hydrologic soil group and land use of the sub-catchments.
- Measurement of the runoff depths for selected rainfall events at the sub-catchments.
- Determination of the curve number.
- Comparison of the curve number with the published values from US SCS.

The steps taken to achieve objective (ii) are as follows:

- Definition of the catchments' boundaries.
- Data acquisition: rainfall, runoff and catchment characteristics from the DID and land surface image from the Remote Sensing Center (MACRES).
- Image processing and land use classifying using MapInfo GIS software.
- Land use area calculation using GIS, and CN determination.
- Derivation of the SCS synthetic unit hydrograph and observed unit hydrograph.
- Comparison before and after land use changes on flood estimation using SCS.

Data Analysis

Three sub-catchments at UiTM Shah Alam campus were delineated in this study with reference from a previous study on urban drainage catchment of the same area done by [3] as shown in Figure 1. The outlets of the three sub-catchments were identified for runoff depth gauging.

Land Classification Using MapInfo GIS

The aerial photograph images obtained from the MACRES were processed further using the ERDAS software and MapInfo GIS to produce digitized maps, so that the land classification could be done.

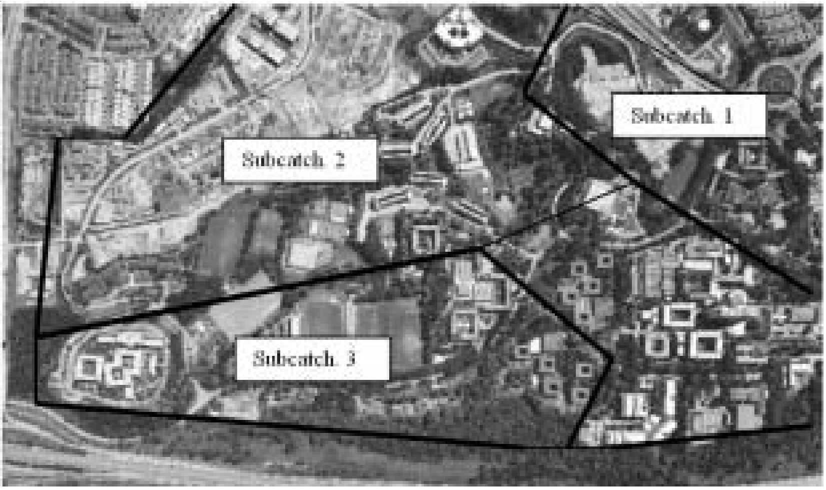

Figure 1: The Three Sub-catchments at UiTM Shah Alam Campus

Results for sub-catchment 1 indicated four major types of land use namely residential area, road, open spaces and swampy area, as shown in more detail in Figure 2. Some checking of the land classification results were done on field, which is known as the *ground truthing* process.

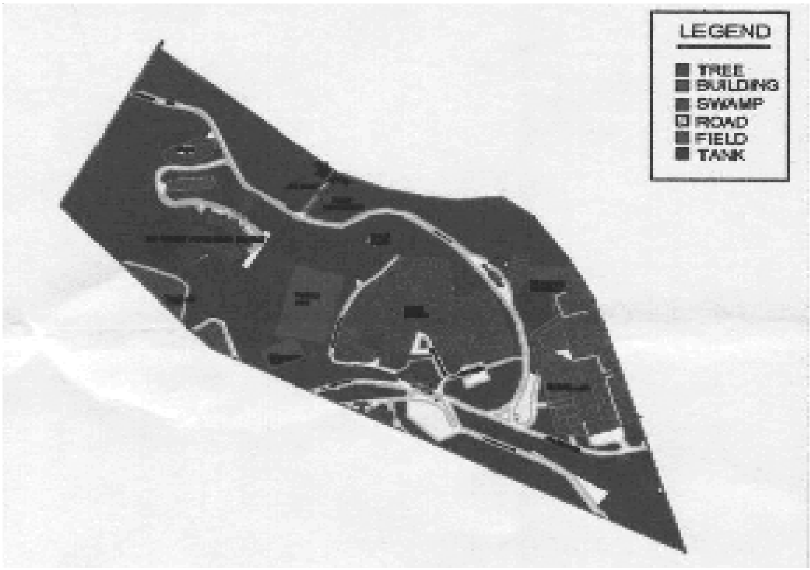

Figure 2: Detail Land Use Map for Sub-catchment 1

(a) (b)

Figure 3: (a) Measurement of Water Level at the Main Outlet of Sub-catchment 1 During a Storm Event (b) The Water Level Gauge

Runoff Depth

The determination of the CN requires the relation between runoff depths and precipitation depths. Data on runoff versus precipitation depths had been collected from several storm events that were occurring in the period of April-July 2005.

In order to obtain the runoff depth, the water level at the sub-catchment outlet had to be measured during the storm event as illustrated in Figure 3. The discharges were calculated by using the Manning's equation as given in Equation (1).

$$Q = \frac{1}{n}\frac{A^{5/3}}{P^{2/3}}S^{1/2} \qquad (1)$$

where Q = runoff/discharges (m^3)

n = manning's roughness coefficient (value depends on the channel)

A = wetted area

P = wetted perimeter

S = slope

Plotting discharge Q, versus time t, for sub-catchment 1 for a storm event would produce a graph as in Figure 4. Area under the curve would be the volume of runoff.

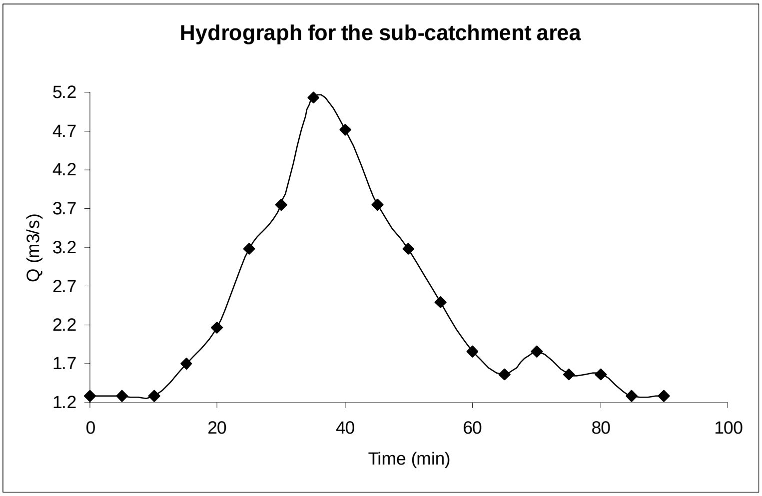

Figure 4: Hydrograph Discharge

The runoff depth (in mm) is calculated as follows:

$$\text{Runoff depth} = q\,(\text{mm}) = \frac{\text{Volume of runoff}}{\text{Catchment area}} \qquad (2)$$

Curve Number Determination

Data of runoff versus precipitation depths for nine storm events had been recorded as given in Table 1. The table represents the relationship

Table 1: Recorded Observations of Rainfalls, Direct Runoff Depth (mm) and AMC

Event (2005)	Runoff (mm)	Precipitation (mm)	AMC
9-Jun	1.50	1.0	I
10-Apr	1.70	1.5	I
4-Jul	2.00	4.0	III
18-Jun	5.03	23.0	I
29-May	3.43	3.0	III
7-Jul	6.63	6.0	II
3-Apr	7.40	11.0	II
25-Jul	1.30	4.0	III
29-Apr	12.00	7.0	II

between runoff, precipitation and antecedent moisture content (AMC) for every storm event observed.

CN was calculated using Equations (3) and (4), and values were plotted for different AMC as shown in Figure 5.

$$CN = \frac{1000}{S} - 10 \tag{3}$$

and

$$q = \frac{(P - 0.21S)^2}{(P + 0.8S)} \tag{4}$$

where, q is the runoff depth, S is potential maximum retention after runoff begins, and P is the rainfall depth.

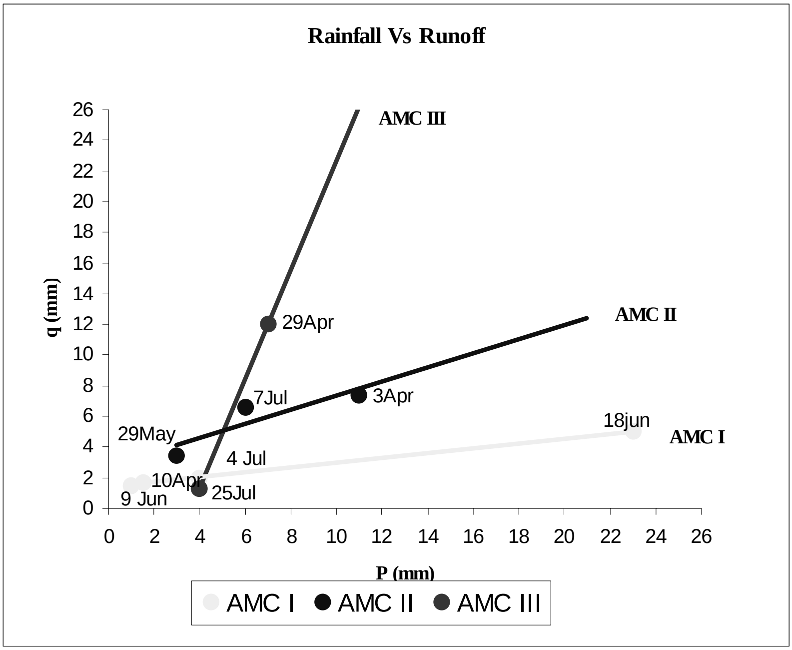

Figure 5: Relationship between Rainfalls and Runoff for a Given AMC

Results and Discussion

Comparison of the Calculated CN with the Published US SCS Curve Number

Based on the land use map for sub-catchment 1, there are four major land use classes namely residential area (25 %), open space (lawns, park, golf courses, cemeteries, woods) (61 %), impervious area (8 %) and swampy area (1 %). Based on the hydrological soil group that was published by the US SCS, similar description to sub-catchment 1, falls under the hydrological soil group A and B with CN is 49 and 69 respectively. The comparison between CN determined from the study and CN number published by the US SCS is given in Table 2.

The steps were repeated for the other two sub-catchments and all comparisons indicated very close similarity (around 8 % difference) between the calculated values based on rainfall-runoff events and published US SCS values.

Table 2: The comparison of calculated CN with the established US SCS Curve Number

Land cover and hydrologic condition (categories published by the US SCS closest to sub-catchment 1 description)	Calculated CN through study by soil group A and B	Established US SCS Curve Number by soil group A	B
Open space (lawns, parks, golf courses, cemeteries): - Fair condition (grass cover 50 % to 75 %)	53	49	69

Effect of Land use Changes on Flood Estimation

In this research, the effect of land use changes on flood estimation was analysed by the application of SCS method which relates the land use with the CN value incorporated in its equation. Wardah *et al*. [4] studied the feasibility of SCS curve number method for Selangor river basin and found that the method is reasonably accurate to be used for peak flow estimation of the catchments. This research investigated the applicability of the method by comparing the synthetic method with the true observed unit hydrograph. Three catchments with runoff stations at Sg. Gombak at Jalan Tun Razak, Sg. Kelang at Jambatan Sulaiman and Sg. Batu at Sentul were selected in this part of the research. Several observations made lead to the same conclusion that SCS method is fairly suitable for the Malaysian catchments under study. Figure 6 illustrates one comparison between observed unit hydrograph from a storm event and the SCS unit hydrograph for the same rainfall duration. The graph indicates the close values of peak discharge, time to peak, and time base between the observed and the SCS unit hydrograph.

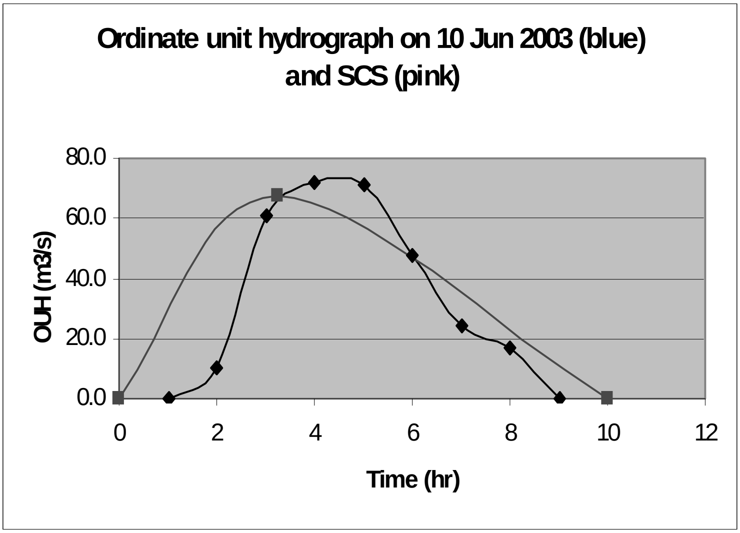

Figure 6: Observed Unit Hydrograph and the SCS Unit Hydrograph Comparison for a Storm Event

Effect of Land use Changes on Flood Estimation Values

After the process of image digitizing, rectification and land use classification using ERDAS and ArcGIS, the CN of Sg. Gombak catchment was calculated as given in Table 3.

$$\text{where } CN_{ave} = \frac{\sum CN_i A_i}{A_{total}} = 88$$

SCS unit hydrograph calculation requires CN in determining time to peak and also peak flow or runoff

Table 3: Calculation of CN for Sg. Gombak Catchment

Land use	Area (mi^2)	Hydrological Soil Group (HSG)	Antecedent Moisture Condition	Curve Number
Lakes	0.264	B	II	79
open space/grass	0.792	B	II	86
Bushes	0.462	B	II	71
Urban	32.817	B	II	92
Forest	2.045	B	II	79
recreational areas	0.330	B	II	69
mixed farming/plantation	6.267	B	II	77
rubber trees	4.024	B	II	81

Peak flow = $Q_p = (484\,A) / T_R$ Equation (5)
Time of rise = $T_R = D/2 + t_p$ Equation (6)
D = effective rainfall duration
and lag time, t_p = $(L^{0.8} (S + 1)^{0.7}) / (1900\,y^{0.5})$ Equation (7)
L = length to divided (ft)
y = average watershed slope (%),
S = 1000/CN – 10

The SCS equations indicate the proportionality of the CN values with runoff values; the higher the CN, the larger is the runoff. Figure 7 shows the variation of peak discharges versus different values of CN.

Conclusion and Recommendation

Conclusion

The CN is an indirect measure of soil potential storage and the values dependent on the land use. With the emergence of latest technology for water resources application, in particular the Geographical Information System software like ArcGIS, the CN can be easily measured. Through remote sensing software like Erdas Imagine and GIS software like MapInfo or ArcGIS, the digitized map of the selected catchment can be developed, land use classified and area measured [5, 6]. Advanced application of the integrated method and tools could be solving the SCS flood estimation directly through the interfacing of programming and GIS software.

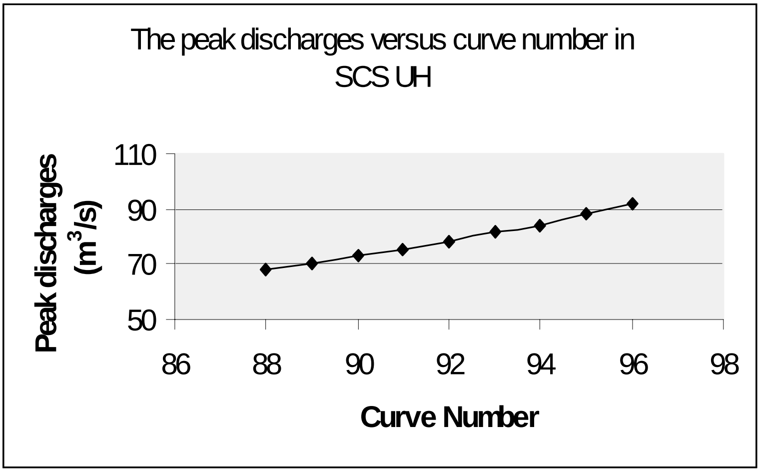

Figure 7: Peak Discharges Variation for Different Values of CN, Case of Sg. Gombak

The research work includes an initial study of the applicability of CN in a Malaysian small urban catchment namely the UiTM campus at Shah Alam. Three sub-catchments with different description of land use were investigated. Rainfall data were collected from the DID gauging station at the campus while runoff data had to be measured manually with a certain degree of difficulties during several storm events, since no runoff gauging station is installed at the campus. Despite the difficulties, some reasonably accurate results were obtained on the runoff. These results were then plotted on graph of runoff versus rainfall to calculate the CN values. The CN values for each small sub-catchment obtained from the field work were then compared with the SCS published curve number for the matched description of land use. The results indicated a close proximity of the CN values obtained from the measured rainfall runoff and the values published by the US SCS. This initial effort produced reasonably sound results in investigating the applicability of the US SCS tabled CN values for Malaysian condition.

Three catchments at upper Klang river basin, namely Sg. Gombak, Sg. Batu and Sg. Kelang were chosen to study the effect of land use changes on flood estimation using SCS method. Several observed unit hydrographs were compared to the SCS unit hydrograph for the same rainfall duration. The results indicated that the estimated values of peak discharges from the synthetic method were not very far from the observed values and the increase in CN will increase the flood estimation.

Recommendation

The country was surprised by what had happened at the vicinity of Taman Pertanian Bukit Cahaya, Shah Alam recently. Many originally vegetated or forested areas had become bare. The land use pattern had been changed for development of several residential areas. Through the research work, we know that bare land or residential areas have higher CN values compared to vegetated area, therefore increase in peak flow is expected to happen, especially when there is no precaution on the extra drainage capacity being taken into consideration. This statement is proven by the occurrence of a 'never-before' flood at Taman Budaya of the Taman Pertanian on November 2004, at the midst of land use changes surrounding it. The research recommends the application of SCS curve number method in studying the effect of land use changes on flooding. The method may need further calibration for Malaysian use. In addition, it is recommended that Malaysian researchers, hydrologists and soil scientists establish nation own curve number for future advancement of the technique as a result of emerging new technologies such as GIS.

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